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Aluminum-Lithium alloys have been introduced to the Aerospace community as a way to decrease weight and improve stiffness over conventional aluminum alloys for structural components. A manufacturing method which has created a great deal of interest for Al-Li aerospace applications is the fabrication of net shape parts by superplastic forming (SPF). Aluminum-Lithium alloys present some unique handling problems and fabrication challenges for established practices in superplastic forming. This paper will discuss the manufacturing challenges and approaches of forming 8091 Al-Li by SPF and provide a brief overview into the material characteristic which make 8091 a successful candidate for SPF aircraft parts.

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22a. NAME OF RESPONSIBLE INDIVIDUAL
James P. Belloto

22b. TELEPHONE (Include Area Code)
(513) 255-2582

22c. OFFICE SYMBOL
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Abstract

Aluminum-lithium alloys have been introduced to the Aerospace community as a way to decrease weight and improve stiffness over conventional aluminum alloys for structural components. A manufacturing method which has created a great deal of interest for Al-Li aerospace applications is the fabrication of net shape parts by superplastic forming (SPF). Aluminum-Lithium alloys present some unique handling problems and fabrication challenges for established practices in superplastic forming. This paper will discuss the manufacturing challenges and approaches of forming 8091 Al-Li by SPF and provide a brief overview into the material characteristics which make 8091 a successful candidate for SPF aircraft parts.

Introduction :

Superplastic forming has provided a means to reduce part count and labor intensity for manufacturing aircraft parts. Titanium and aluminum alloys have been successfully used as SPF structures on several different types of aircraft. The emergence of composite materials for use on aircraft structural and non-structural elements has initiated a drive in the metals industry to produce alloys of high strength and toughness, light weight and which have excellent thermal properties. The Al-Li alloys were developed as low density high stiffness materials which would be competitive with composite materials and allow conventional metal manufacturing methods to be applied.

Several of the Al-Li alloys were developed for both conventional and superplastic forming applications. Rockwell is currently examining the characteristics and formability of 8091 Al-Li which is processed for superplastic capabilities.

Material Selection and Characterization :

The three alloys examined for the SPF program were 8090, 8091, and 2090 Al-Li (Refer to Table 1). Samples of the alloys were obtained from Alcan, Alcoa and Reynolds prior to the onset of the program. The materials were examined for SPF elongation, post SPF strength and for production availability of the alloy. The results from the analyses yielded 8091 as the most promising Al-Li alloy for both forming and for post SPF strength after heat-treatment (Table 2).

Table 1 : Ingot metallurgy alloys examined for SPF.

	Li	Cu	Mg	Zr	Al
8090	2.45	1.3	.75	.12	Rem.
8091	2.60	1.9	.55	.12	Rem.
2090	2.30	2.5	---	.12	Rem.

8091 Al-Li was obtained in three thicknesses (0.065", 0.090" and 0.125") from Alcan in the "superplastic" condition. SPF characterization studies were

Table 2: Aluminum-Lithium Mechanical Properties

Alloy	Highest Statistical -T62 Properties			Tensile Properties for -T8 condition			SPF Prestrain of 0.76 before Heat Treating to -T62		
	Ftu (ksi)	Fty (ksi)	Elong. (%)	Ftu (ksi)	Fty (ksi)	Elong. (%)	Ftu (ksi)	Fty (ksi)	Elong. (%)
8090 - XXXA	69	59	12	71.5	56.2	7	60.5	45.6	5.5
8090 - SP	69	59	12	70.2	56.2	5	49.8	42.3	2.5
8091 - SP	69	59	12	77.67	62.5	8	64.7	49.4	5.5
2090 - SP	69	59	12	76.5	71.0	6	54.2	44.4	4.5

initiated at the Rockwell science center on all three gauges of material. The initial group of tests were performed to optimize the forming temperature and achieve the maximum SPF elongation in the part. The optimum forming temperature, used for the remainder of the characterization tests, was found to lie between 950 and 990 oF for all three gauges (Figure 1).

The initial SPF characterization tensile tests used stepped strain rates to determine preliminary flow stress levels and elongation data.[1] The stepped tests were followed by single strain-rate tensile tests. These tests resulted in lower overall SPF elongations than multiple strain-rate tests. Optimization of the SPF elongation resulted in the use of an initial strain rate followed by a slower strain rate for all forming and test operations. The two step approach to forming allows the material to convert from static grain growth to dynamic recrystallization and grain growth. This combination allows greater uniaxial SPF elongations to be achieved during the forming process without causing necking or areas of localized thinning in the part. The strain rate used during the initial phase of the forming test (10-3) resulted in high levels of flow stress in the material. The second phase strain rate - typically a decade less than the initial strain rate - had reduced flow stress levels which remained nearly constant throughout the remainder of the test (Figure 2).

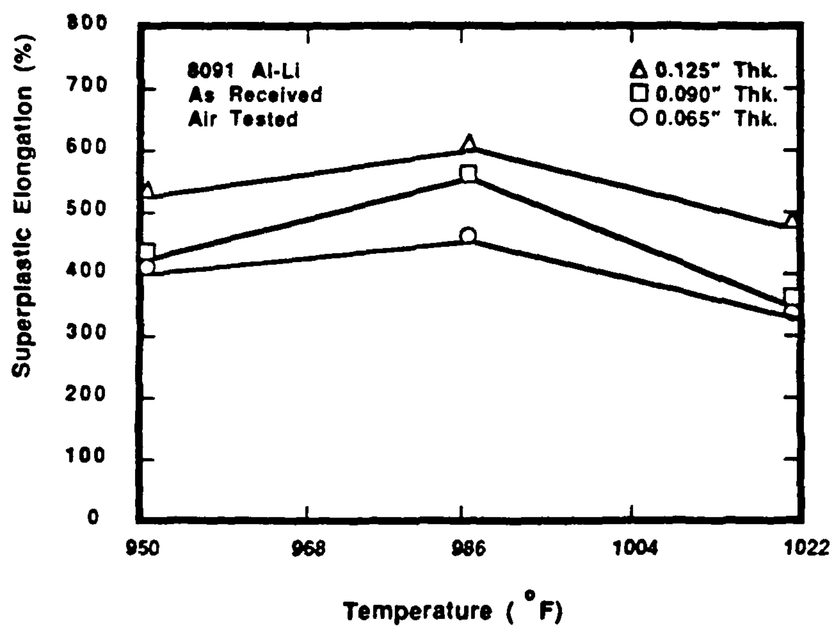


Figure 1: Elevated Temperature Tensile Tests were conducted to determine the maximum SPF elongation in the part. The optimum SPF temperature was used throughout the remainder of the tests.

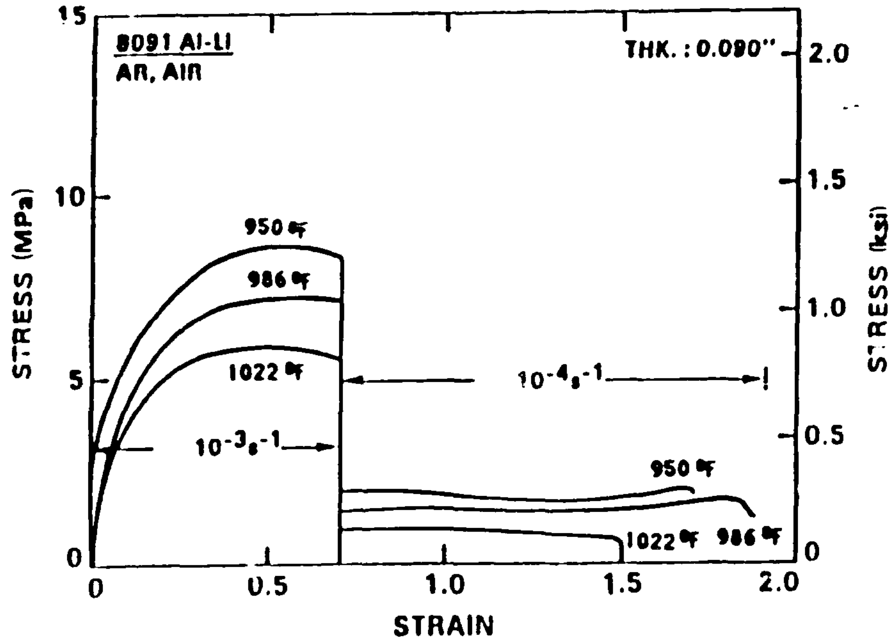


Figure 2: Flow stress as a function of Engineering strain for SPF 8091 Al-Li using optimum strain rates.

As with 7475 aluminum, aluminum-lithium alloys require back pressure to supress cavitation or intergranular voids during the forming cycle.[2,3,4] Tensile tests were perfomed with different levels of back pressure using optimized temperature and strain rate profiles. Back pressure values above 200 psi delayed the onset of cavitation from 25% to 200% engineering strain, which allowed SPF elongations to be increased from 400% (in air, no back pressure) to 1300% (Figure 3). The final phase in the characterization study was the optimization of post SPF properties. The optimal mechanical properties for 8091 Al-Li required a post SPF heat-treatment which would produce sufficient strength without causing embrittlement in the material.

The heat-treatment optimization work has been conducted at Washington State University (WSU)[5]. The heat treatment optimization has examined the solution heat-treatment parameters, quench sensitivity and artificial aging parameters for SPF 8091 Al-Li. The initial heat-treatment tests were conducted during the same time period as the initial SPF characterization studies with as-received (AR) material. Once the optimum SPF tensile parameters were obtained, small test pans were formed and provided to WSU for optimum heat treatment verification.

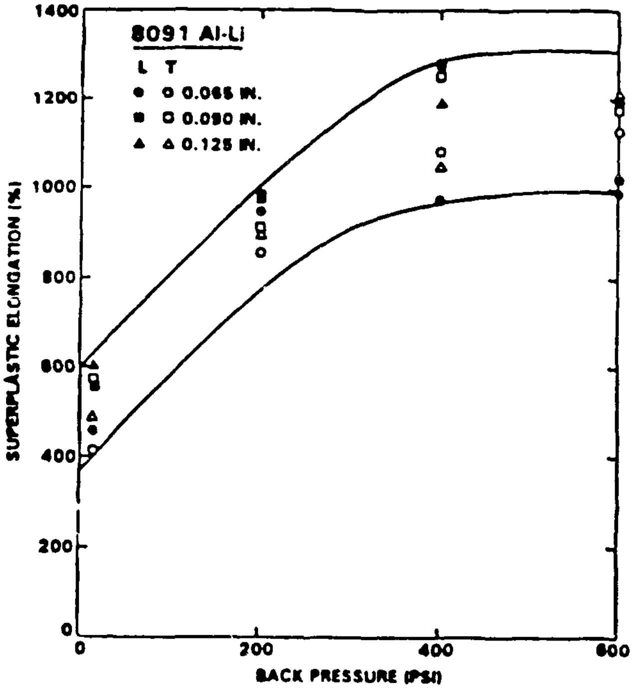


Figure 3 : Superplastic elongation is effected by the amount of back pressure used during the forming and test operations.

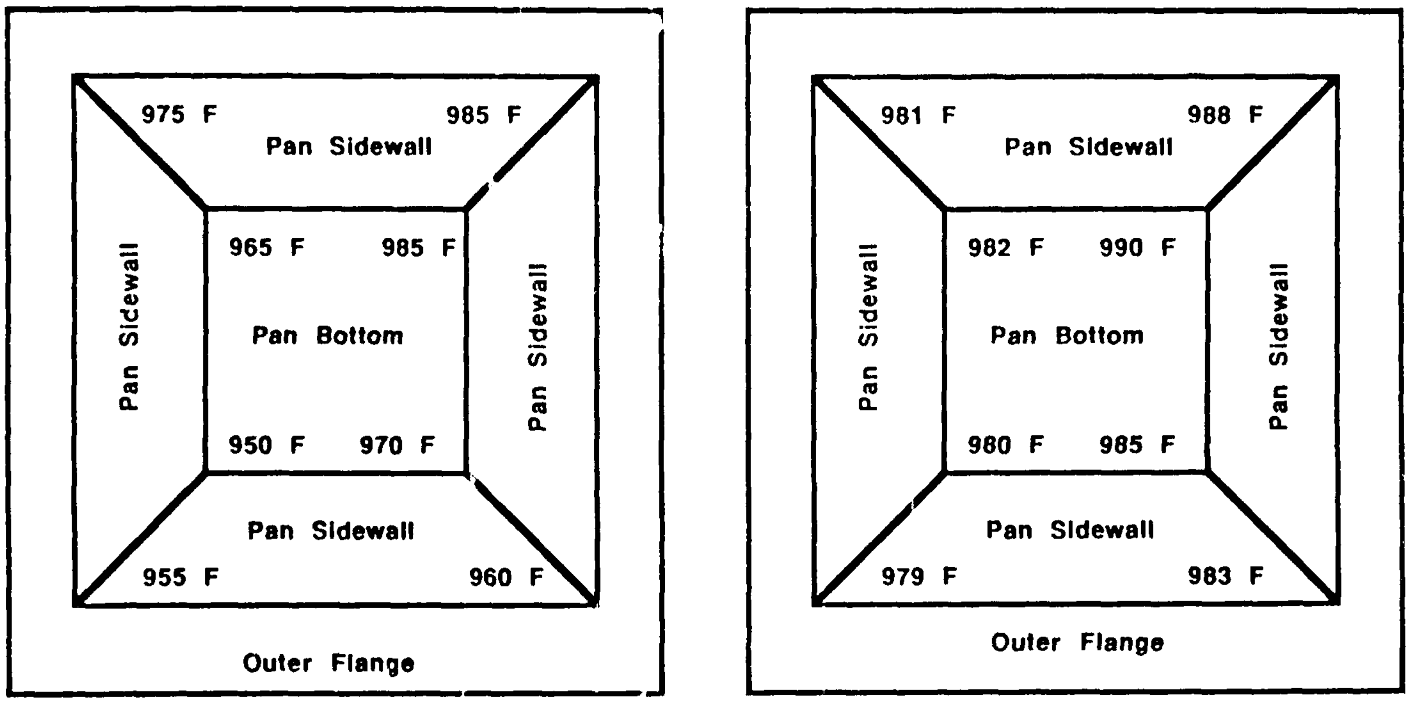
Forming with 8091 Al-Li :

Forming studies were initated using the optimum tensile parameters. The forming temperatures for 8091 Al-Li are not significantly different than those for 7475 aluminum, making the choice of tooling materials consistant with past work on 7475 Al.[6] There is a potential for tooling corrosion with the Al-Li alloys at elevated temperatures; this problem could be eleviated by using a corrosion-resistant steel or by applying a non-reactive, glassy coating to the tool. Such a glassy coating on the tool would assist the releasing agent in lubrication during the forming operation, would ease part removal from the tool and might allow easier tool cleaning. The releasing agent which has proved successful for 7475 aluminum (boron-nitride) appears to be excellent for 8091 Al-Li. There does not appear to be any problems with excessive build-up of boron-nitride of the tool surface although the amount of producibility parts formed with the same tool has been limited to ten. Production use of the releasing agent may require further investigation.

The types of tooling which appear to be the most flexible for the manufacturing environment are a die box with inserts. The die box can be platen heated or integrally heated but must be well insulated to prevent large temperature gradients over the surface of the tool. 8091 Al-Li is very sensitive to thermal gradients in tooling which can be seen in Figure 4. The flow stress, as shown in Figure 2, increases with a decrease in forming temperature. An increase in flow stress can cause cavitation along with premature failure in the part. The thinning profiles for two pans with different temperature gradients show changes in the way the part conformed to the surface of the tool. Figure 5 shows the thinning profile of a pan formed with several thermal gradients over the surface of the tool. Figure 6 represents a part with more uniform thickness distribution and thermal profile. Cavitation analysis for a part formed with several thermal gradients versus a part with excellent temperature control can be seen in Figure 7. Temperature control of ± 5 °F is an optimum forming condition but ± 10 °F does not appear to cause extreme difficulty with the material thinning profile (Figure 4, 5 and 6).

The part blank should be hot loaded to eliminate undesireable effects associated with long exposure times at elevated temperatures. Loading the part blank into a die at room temperature (cold loading) and subsequently heating the die-part blank system to the optimum forming temperature will cause excessive grain growth and oxidation in the material. Grain growth if allowed to continue for long periods of time will eliminate all superplastic characteristics in the material. The oxidation of Al-Li alloys will allow lithium-oxide or -hydroxide to be formed which can degrade the final mechanical properties of the part.

The optimum strain rates, forming temperature and back pressure obtained from tensile analysis were used to fabricate the producibility parts for the program. The first four parts used strain levels up to 1.0 for the initial phase after which the strain rate was reduced for the remainder of the forming cycle. Pressure-time cycles were developed on an in-house computer system which models both the tool configuration and the strain hardening behavior of the material during the cycle. The initial parts failed as a result of the rapid forming rate and of improper temperature control during the process. The amount of first stage strain was decreased for the second batch of producibility tests. The process parameters (forming temperature, back pressure control and pressure-time cycle control) were also monitored closely to achieve better formability than pans 1 through 4. The pans fabricated under the new conditions (pans 5 through 10, batch 2) appeared to have improved uniformity in the thinning profiles but orange peel texturing was observed on several of the pans along with areas of excessive thinning



Temperature Control A **Temperature Control B**

Figure 4: Thermal profiles of the producibility tool surface shows large thermal gradients (A) versus a uniform temperature profile (B). Pan "A" may have areas which have not completely formed or have excessive orange peel texturing. Pan "B" should have better formability than pan "A".

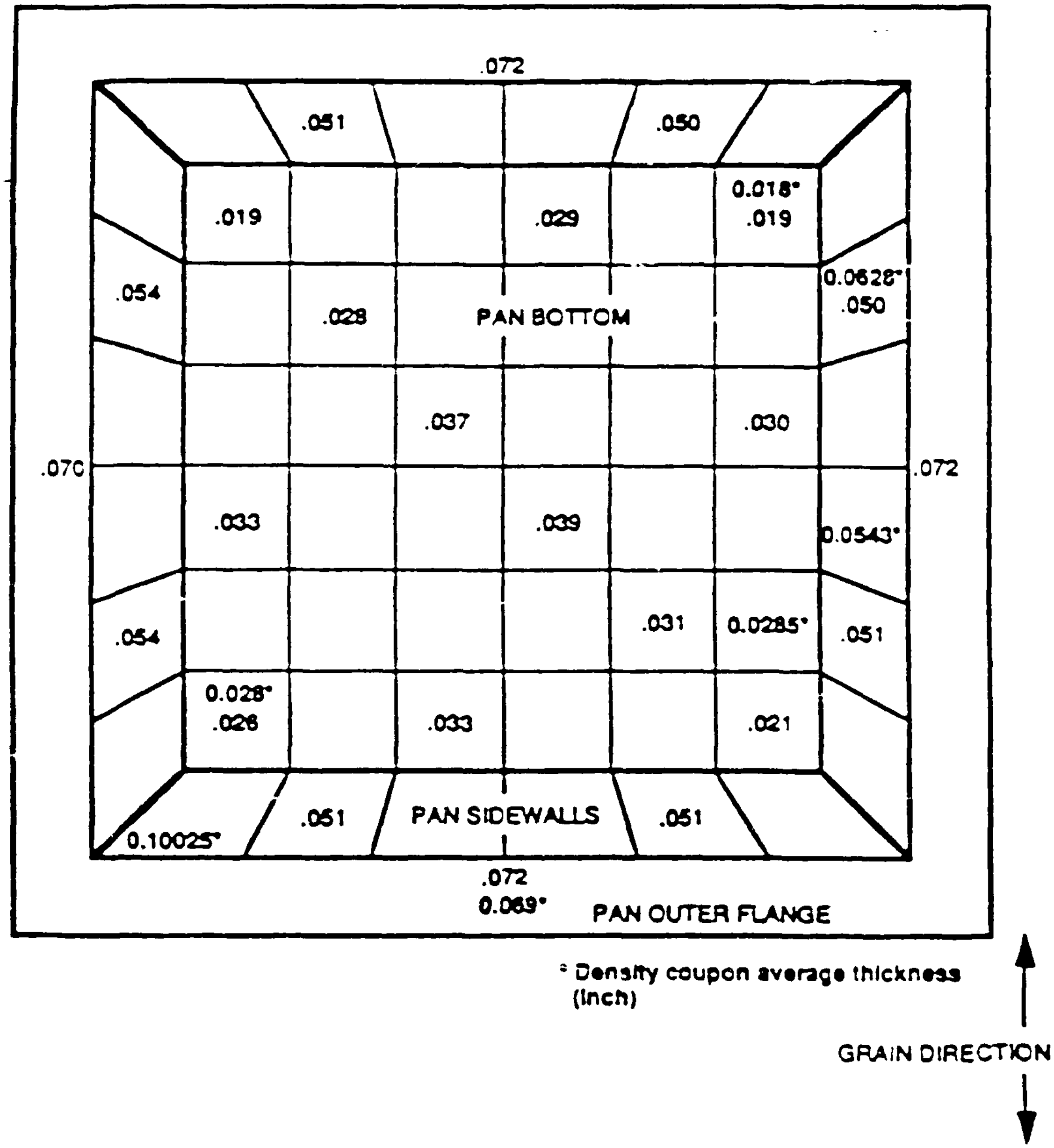


Figure 5: Thinning profile for a producibility pan formed with different temperature gradients along the tool surface. Original thickness of the sheet prior to SPF was 0.090".

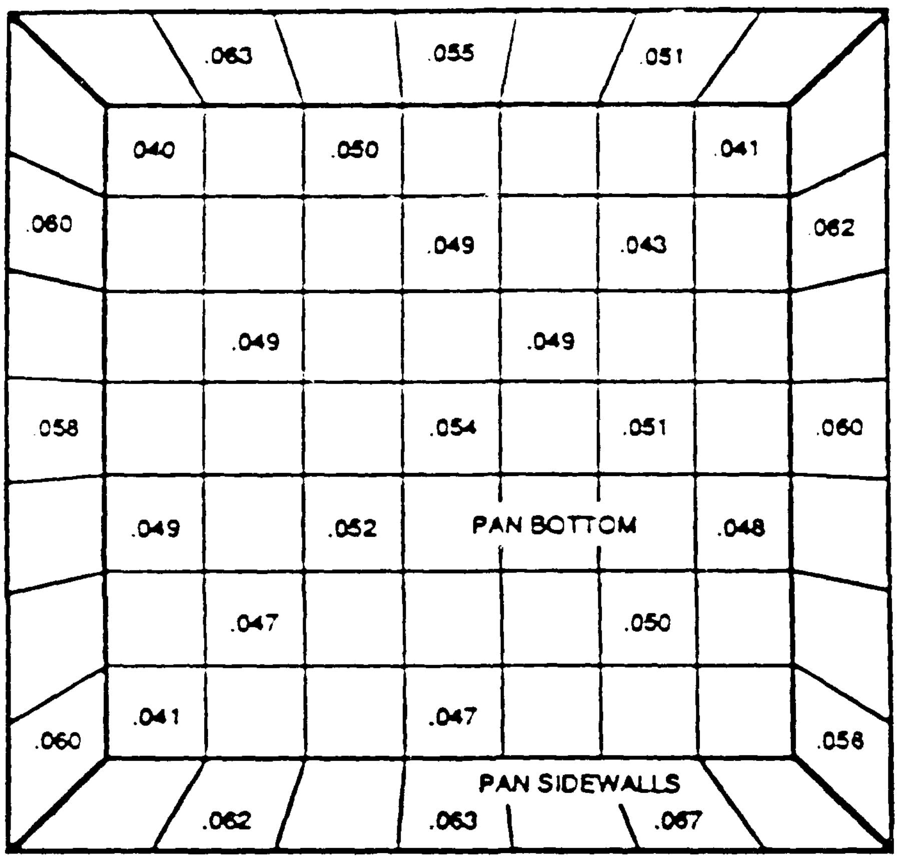
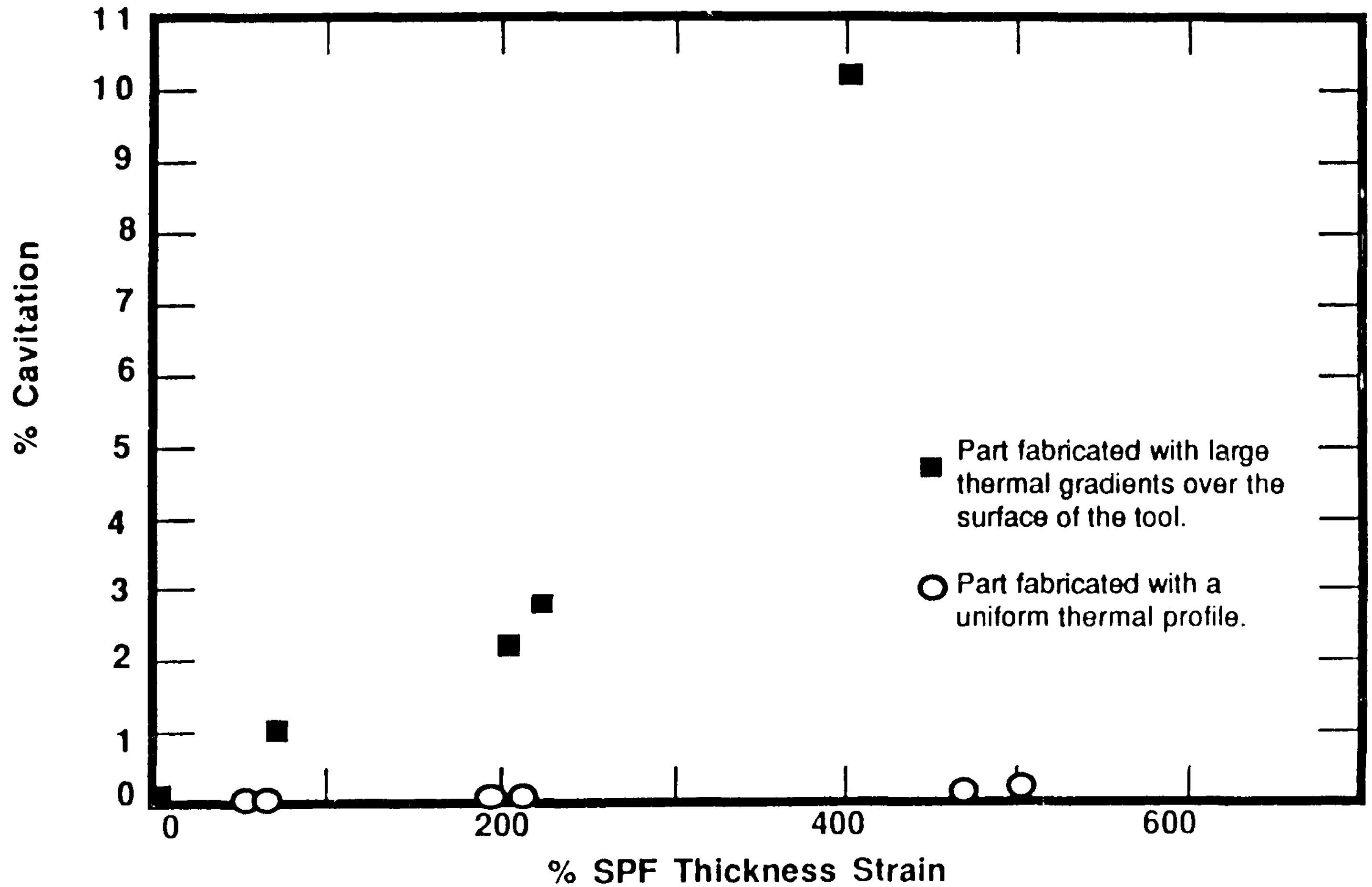


Figure 6: Thinning profile for a producibility pan formed with a uniform thermal profile. Original thickness of sheet prior to SPF was 0.090".

Figure 7: Cavitation for pans formed with 400 psi back pressure but with different thermal profiles on the tool surface while forming.



along the side walls. A modification to the strain rate transition was made which allowed the parts (third batch of producibility parts, pans 12 through 14) to be fabricated without any apparent flaws (Figure 8). The pans in all three groups of tests did not show any evidence of highly directional behavior. Thus, anisotropy did not appear to be a major issue for SPF 8091 Al-Li. All of the producibiltiy pans were hot unloaded. The 8091 Al-Li appears to be significantly softer than previous SPF 7475 aluminum during removal from the tool and will have to be handled in such a manner which will prevent distortion of the formed part.

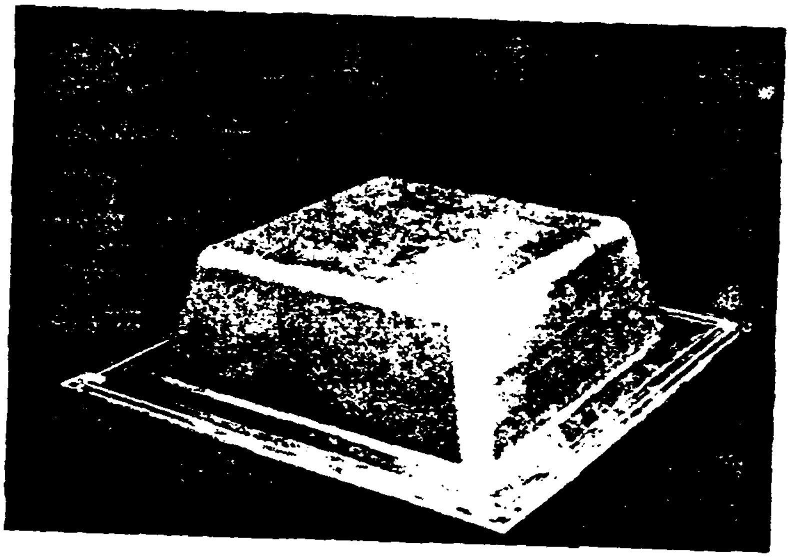
Cavitation analysis was perfomed on both the second and on the third batch of producibility parts. The results from the analysis can be seen in Figure 9. The measurements for the parts formed in the third batch did not show any evidence of cavitaion up to 500% thickness strains.

Heat Treatment Optimization :

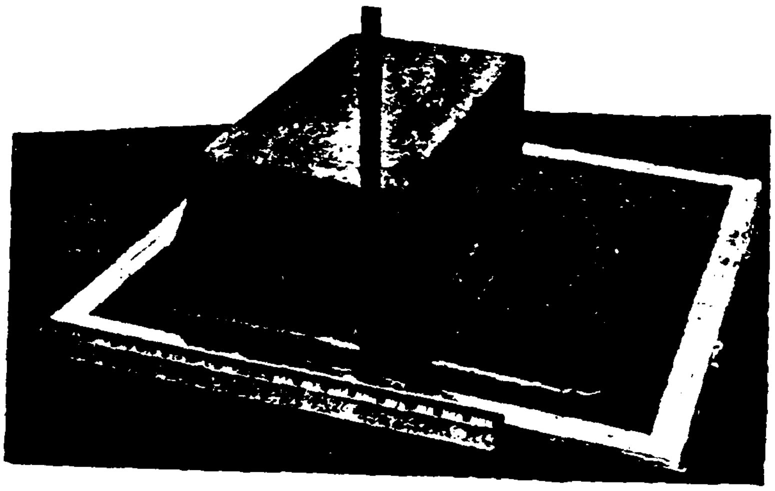
Aluminum-Lithium materials require solution heat-treatment at high *temperatures* to assure dissolution of the precipitates into the matrix. The solution heat-treatment times should be kept at a minimum to prevent the loss in desireable properties from oxidation. An artificial age of the solution heat-treated parts appears to produce desired -T62 strength levels in the material (Table 2). The strength of as-received and SPF material after heat-treatment can be seen in Figure 10.

Aircraft Applications for SPF 8091 :

Applications that have been examined in the past for SPF conversion are built up structure with high part count and high labor intensities. SPF conversion studies for 8091 Al-Li use these criteria for choosing a favorable part design along with high stiffness and low weight requirements. Both primary and secondary structures with beaded or sinusoidal stiffeners (replacing extrusions either bonded or mechanically fastened) appear to reduce the labor intensity of a part (labor intensity is defined as the amount of different as well as repetitive steps required to fabricate a part) and overall part cost. Parts that are conventionally complex in design and require multi-stage forming operations also have reduced cost and labor intensity values. The reductions in cost and labor intensity along with several other factors are used to determine the cost effectiveness or "tradability" of a conventional

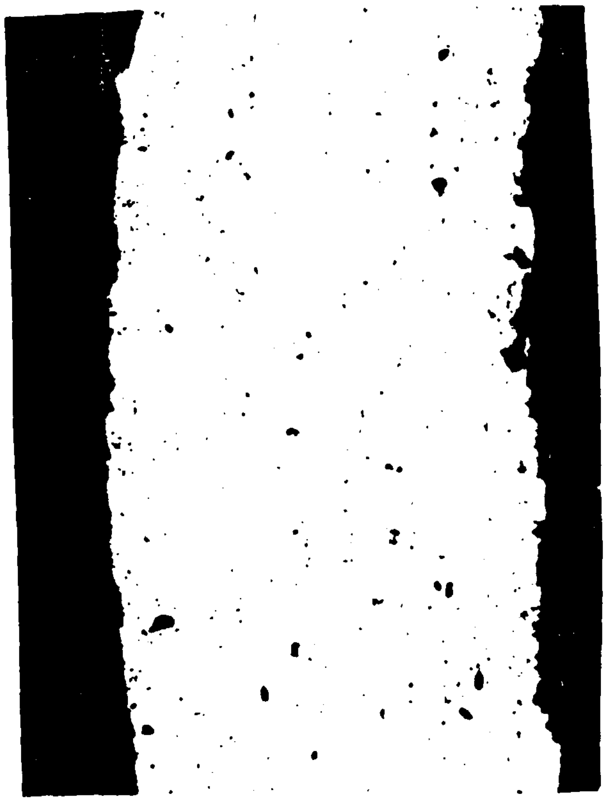


18" x 18" x 6" producibiltiy pan

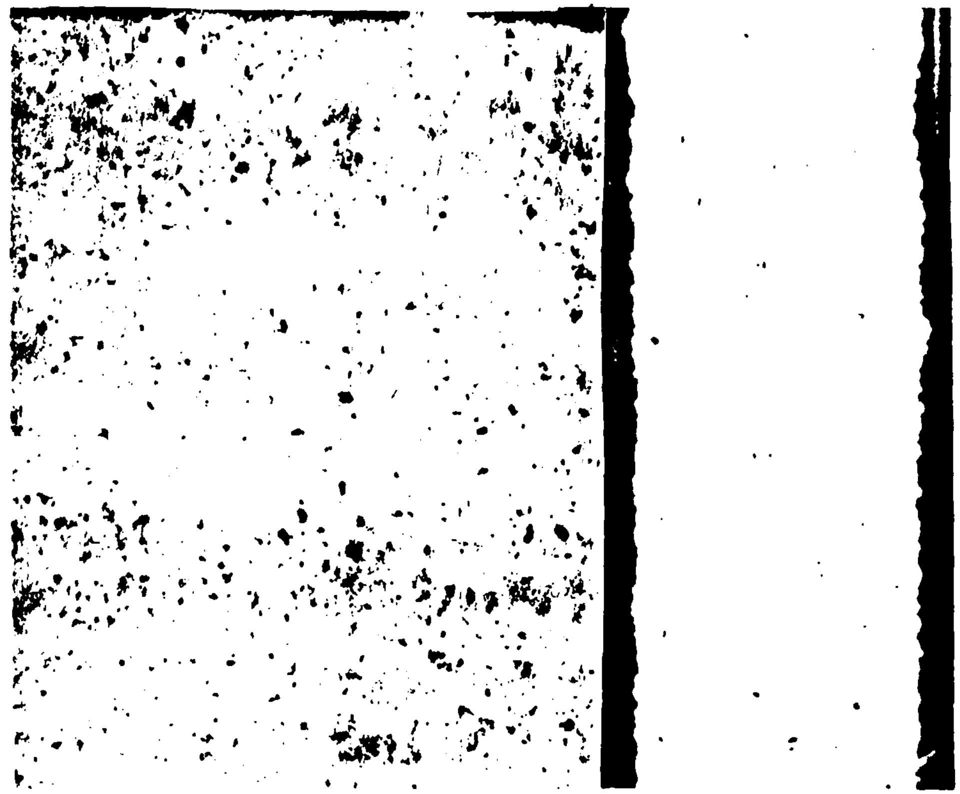


18" x 9" x 6" producibility pan

Figure 8: 8091 Al-Li SPF producibility parts formed with a modified strain rate transition cycle.



Magnification 100 X
(A)



Magnification 100 and 200 X
(B)

Figure 9 : Cavitation in 8091 Al-Li producibility pans fomed with non-unifom thermal distribution (A) and with a uniform thermal distribution (B) at 400 to 500 % localized thinning.

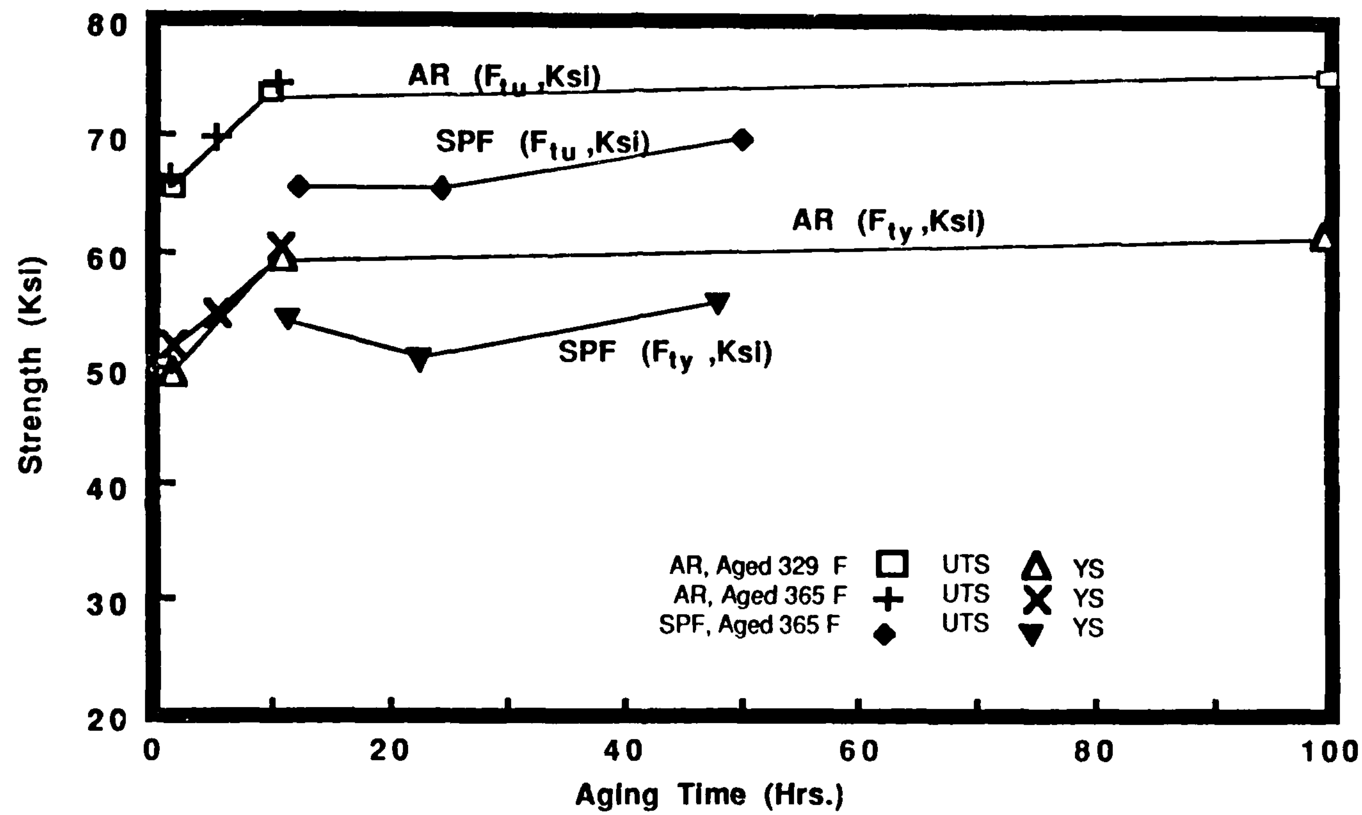


Figure 10 : Tensile strength of 8091 Al-Li material in the as-received plus heat treated and the SPF plus heat treated conditions.

design to a SPF structure. SPF Al-Li alloys provide a familiar alternative to many types of built-up structural components and have the advantage of being a simple forming process, similar to SPF 7475 aluminum fabrication methods with the advantage of having shorter forming cycles. .

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